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RESEARCH MEMORANDUM

RESULTS OF FLIGHT TESTS TO DETERMINE THE DRAG OF FINITE-LENGTH CYLINDERS AT HIGH REYNOLDS NUMBERS FOR A MACH NUMBER RANGE OF 0.5 TO 1.3

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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RESEARCH MEMORANDUM

RESULTS OF FLIGHT TESTS TO DETERMINE THE DRAG OF FINITE-LENGTH CYLINDERS AT HIGH REYNOLDS NUMBERS FOR A MACH NUMBER RANGE OF 0.5 TO 1.3

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SUMMARY

Results of a free-flight investigation to determine the drag of circular, finite-length cylinders are presented for a Mach number range of about 0.5 to 1.3. Fineness ratios of the cylinders tested were 15, 30, and 60. Results of previous experimental tests of circular cylinders having infinite fineness ratios are included in this paper for comparison.

For supersonic speeds, the drag of circular cylinders is largely independent of fineness ratio and Reynolds number. At subsonic Mach numbers, the drag of finite-length cylinders (fineness ratios of about 60 and below) increases as their fineness ratios increase.

INTRODUCTION

The interest that has existed in forces and moments experienced by bodies of revolution in inclined flight has increased with the present-day missiles and supersonic aircraft where the body is a principal component of the configurations. The method of reference 1 to determine the aerodynamic characteristics of bodies of revolution at angles of attack involves the use of the viscous cross forces existing on the bodies. Because of the lack of experimental data which can be used in the determination of these viscous cross forces at cross-flow Mach numbers in the region of unity, the National Advisory Committee for Aeronautics has made some free-flight tests to determine the drag of circular cylinders of finite fineness ratios.

Cylinders having fineness ratios of 15, 30, and 60 were tested. The cylinders were mounted on test bodies in such a manner as to minimize interference effects.

The results of these tests are presented herein and are compared with previously obtained experimental drag data for circular cylinders of infinite lengths.

The free-flight tests were conducted at the Pilotless Aircraft Research Station at Wallops Island, Va. The Mach number range was from 0.5 to 1.3 and the range of the corresponding Reynolds numbers based on cylinder diameter was from 1.25×10^5 to 7.25×10^5.

SYMBOLS

C_{D_T} total configuration drag coefficient based on the test body frontal area

C_D cylinder drag coefficient based on cylinder frontal area

M Mach number

R Reynolds number

L/D fineness ratio

L length of cylinder, inches

D diameter of cylinder, inches

MODELS AND TESTS

The general arrangement for the three test configurations used in this investigation is shown in figure 1, and a photograph of a typical model is shown in figure 2.

The basic body on which the cylinders were mounted was a simply constructed circular-cylindrical wood body having a special fin assembly. The rectangular end plates mounted on the ends of the horizontal fins provided the necessary stabilizing area in the vertical plane. The cylinders, in turn, were mounted on the end plates so that essentially half a cylinder was mounted on each end plate; the leading edges of the end plates were beveled on the side away from the cylinders in order to minimize the flow disturbances over the cylinders. The fin assembly and cylinders were constructed of steel.

The models were propelled by a two-stage rocket arrangement. The first stage was a high-velocity aircraft booster rocket equipped with four fins; the second stage was a 3.25-inch aircraft rocket contained within the model.

Test data were obtained and reduced by the methods described in reference 2. In figure 3, the Reynolds number during flight, based on cylinder diameter, is plotted against Mach number for each cylinder tested.

The accuracy of the tests is estimated to be as follows: cylinder drag coefficients within ±0.02 at $M = 0.8$, ±0.01 at $M = 1.20$, and Mach number within ±0.01.

RESULTS

Total-configuration drag coefficients plotted against Mach number are shown in figure 4 for a typical test configuration. Data points are shown in this plot to give the reader a representative example of the number of data points and their scatter from which the faired curves of figure 5 were obtained.

Figure 5 shows the variation of total-configuration drag coefficients (based on model frontal area) with Mach number for the three cylinders tested. Also shown in this figure are the drag coefficients of the basic test model.

Cylinder drag coefficients (including cylinder end-plate interference drag and based on cylinder frontal area) for the three cylinders tested, were obtained as the difference between the total-configuration drag and the drag of the basic body and are shown in figure 6 plotted against Mach number. Also shown in this figure for comparative purposes are some supersonic cylinder drag coefficients determined experimentally by Stanton (ref. 3) and Busemann (as shown in ref. 4). The cylinders tested by Stanton were of infinite fineness ratios. Busemann's test was made in a blow-down tunnel with the cylinder extending through the jet. Because deviations from the uniformity of the flow existed at the edges of the jet, the effective fineness ratio of the cylinder was indeterminant; however, it is believed that it would approach infinity.

The variation of the drag coefficients with Mach number of the cylinders of the present tests forms a band which, at $M = 0.7$, centers around approximately 1.2, increases to about 2.0 at $M = 0.95$, and then decreases with increasing supersonic speeds to approximately 1.5 at $M = 1.3$. The coefficients within this band show that the drag of cylinders increases as their fineness ratios increase at subsonic Mach numbers. At supersonic speeds, however, the width of the band of the coefficients has decreased and no apparent trend of the drag curves relative to each other exists; further, the supersonic drag coefficients determined by Stanton and Busemann for cylinders of effective infinite fineness ratios, and at Reynolds numbers much lower than those of the present tests, appear consistent with the coefficients of the present tests. From the comparative agreement of the results of these tests, it appears that cylinder drag coefficients are largely independent of Reynolds number and fineness ratio at supersonic speeds. (Although the Reynolds number of the Busemann test is not listed in reference 4, it was confirmed by Dr. Busemann that his test was made at a Reynolds number of approximately 50,000.)

The dip existing in the drag-coefficient curves for the two higher fineness ratio cylinders around $M = 0.825$ may be the result of transition from laminar to turbulent flow around the cylinders; this result is considered further in the discussion of figure 7. Similar dips in cylinder-drag curves were shown in reference 5 where an unsuccessful attempt was made to correlate the occurrence of the dips with wake-width variation. The lack of a dip in the drag curve of the cylinder having a fineness ratio of 15 may possibly be explained by more predominant end effects existing for this lower fineness ratio.

The drag coefficients (based on cylinder frontal area) for the cylinders tested are shown in figure 7 plotted against Reynolds number. Also shown in this figure, for comparative purposes, are previously obtained experimental drag coefficients of cylinders from references 6 to 8.

The results of the two larger cylinders of Stack's tests (ref. 7) very clearly define the pronounced effects on the drag coefficients of cylinders when transition from laminar to turbulent flow occurs prior to the critical Mach number. When this effect is remembered and the trend of the initial portions of the drag curves of the present tests is noted, it appears that the dips in the drag curves for the two higher-fineness-ratio cylinders may be attributed to the occurrence of the critical Mach number followed by transition, the compressibility effects being predominant.

At subcritical Mach numbers and Reynolds numbers the drag of the cylinder having a fineness ratio of 60 agrees with that for cylinders of infinite fineness ratios; thus, when determining drag, cylinders with fineness ratios of about 60 or greater may be considered to be of infinite length.

CONCLUSIONS

Flights tests in a Mach number range of about 0.50 to 1.3 of circular finite-length cylinders and the results of previous experimental tests of circular cylinders having infinite lengths lead to the following conclusions:

1. Drag of circular cylinders at supersonic speeds is largely independent of fineness ratio and Reynolds number.

2. At subsonic Mach numbers, the drag of finite-length cylinders (fineness ratios of about 60 and below) increases as their fineness ratio increases.

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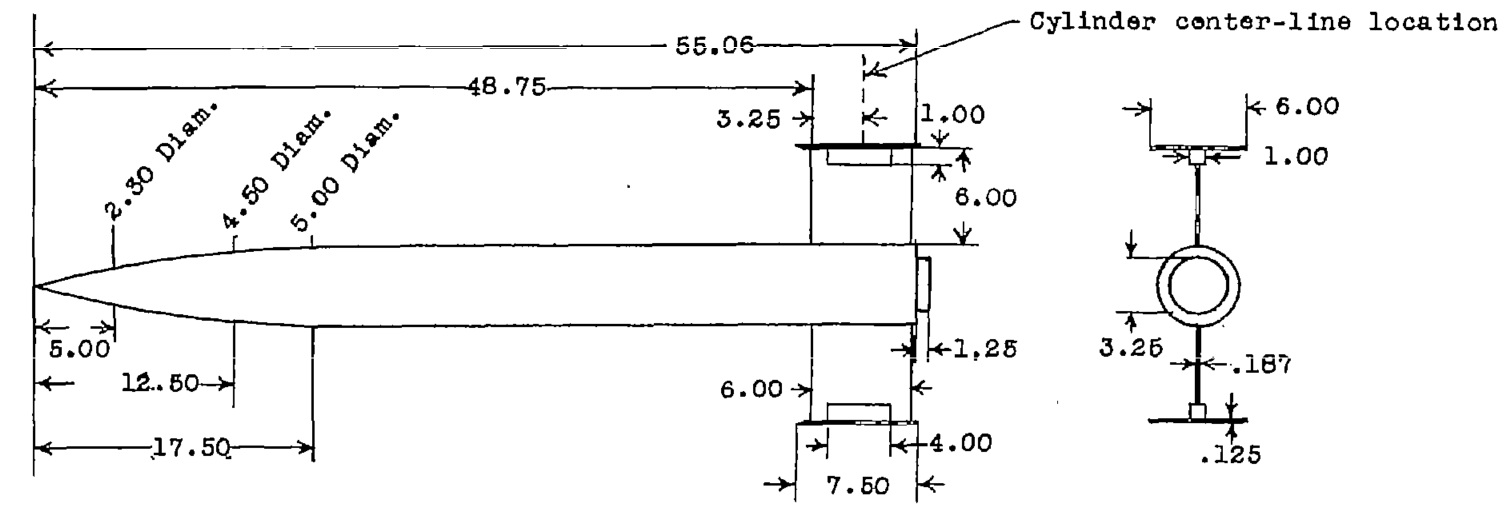
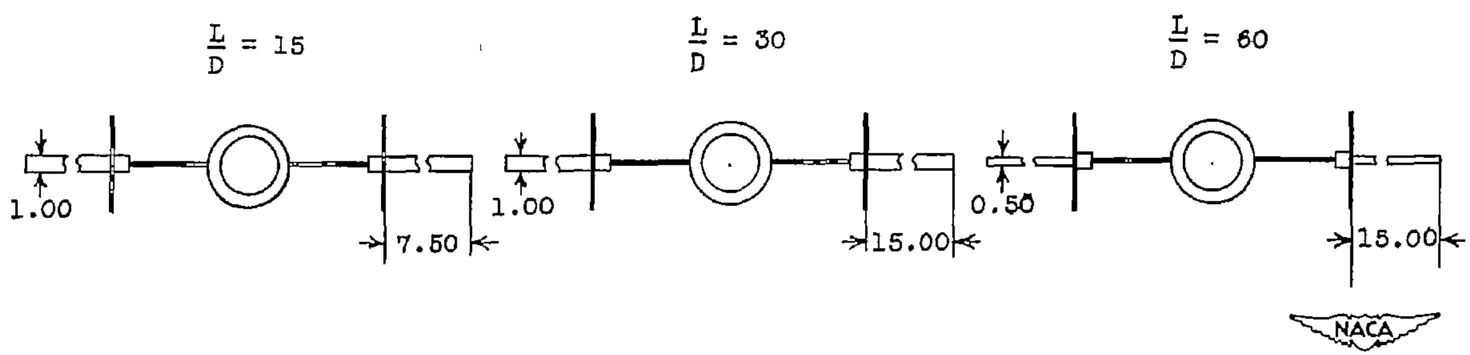


(a) Basic test body.



(b) End views of the cylinder configurations.

Figure 1.- General arrangement of model configurations showing the basic test body and the three cylinder configurations tested. All dimensions are in inches.

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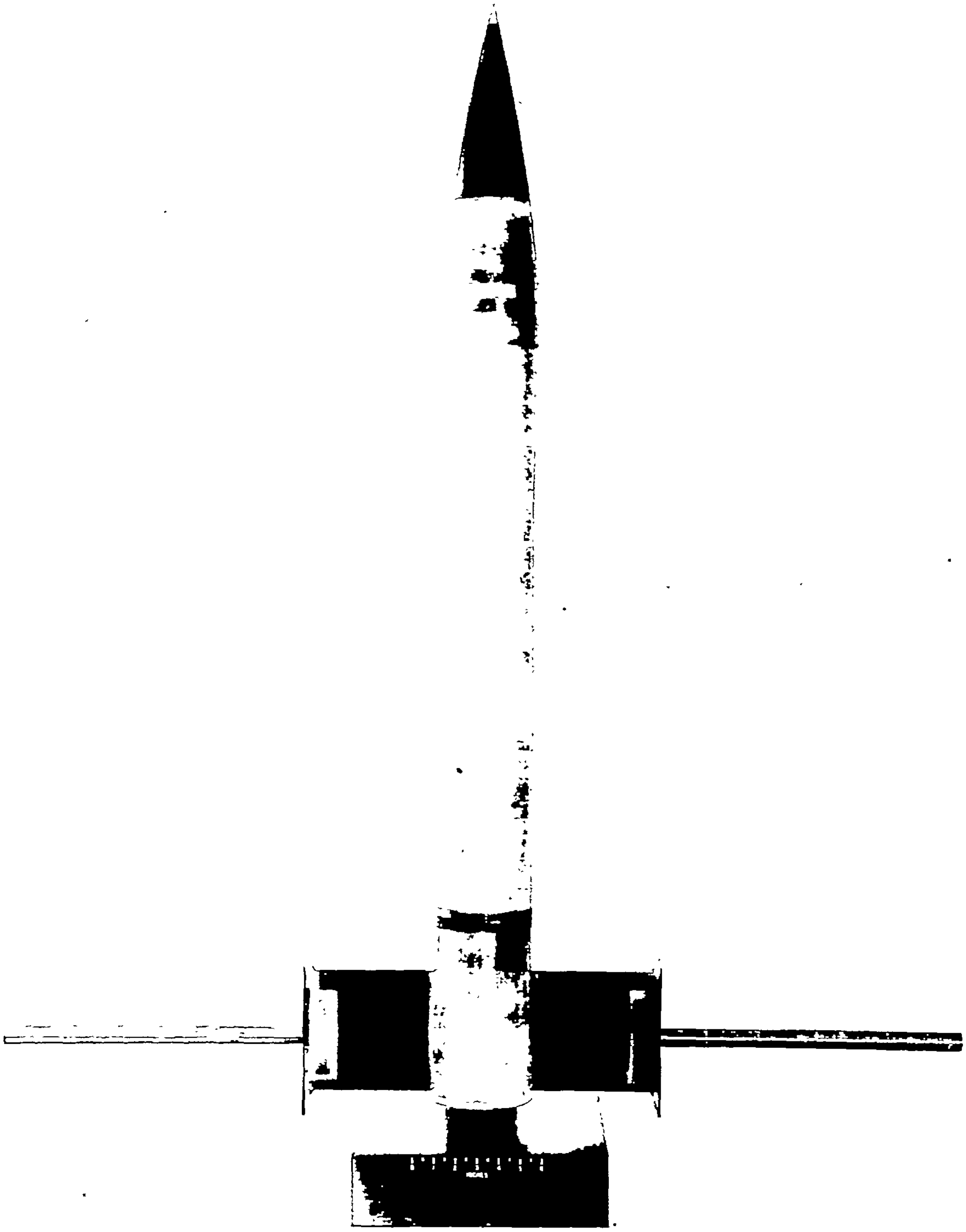

Figure 2.- Plan view of a typical cylinder configuration investigated. $\frac{L}{D} = 30$.

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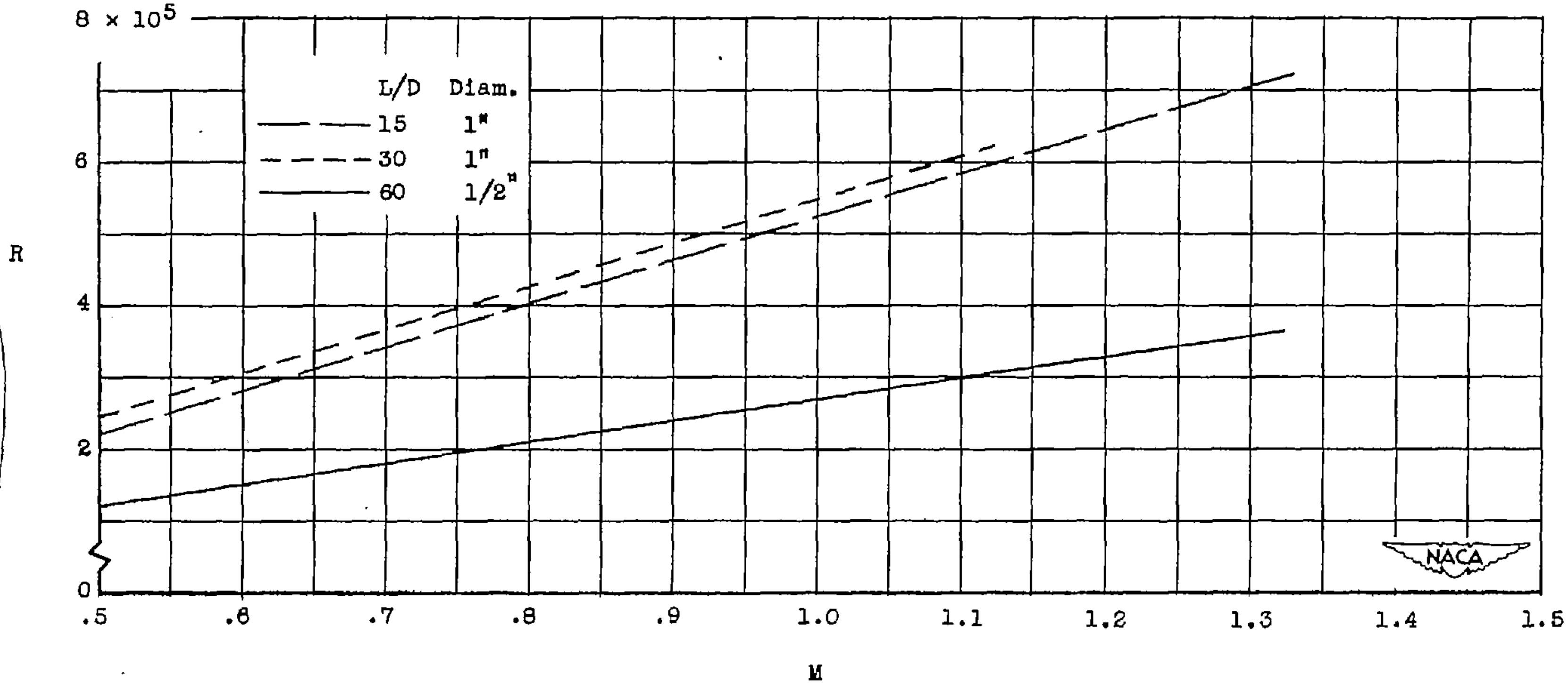

Figure 3.- Variation of Reynolds number in flight, based on cylinder diameter, with Mach number for the cylinders tested.

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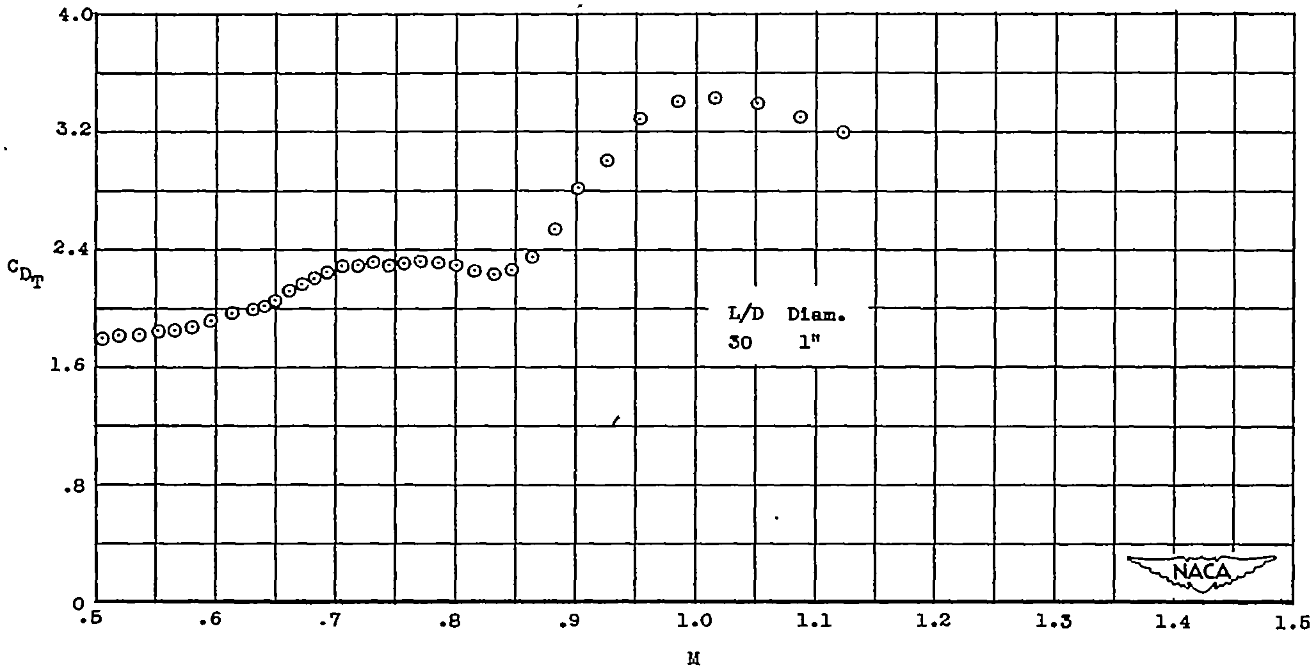

Figure 4.- Variation of total drag coefficients with Mach number for a typical cylinder configuration showing data points.

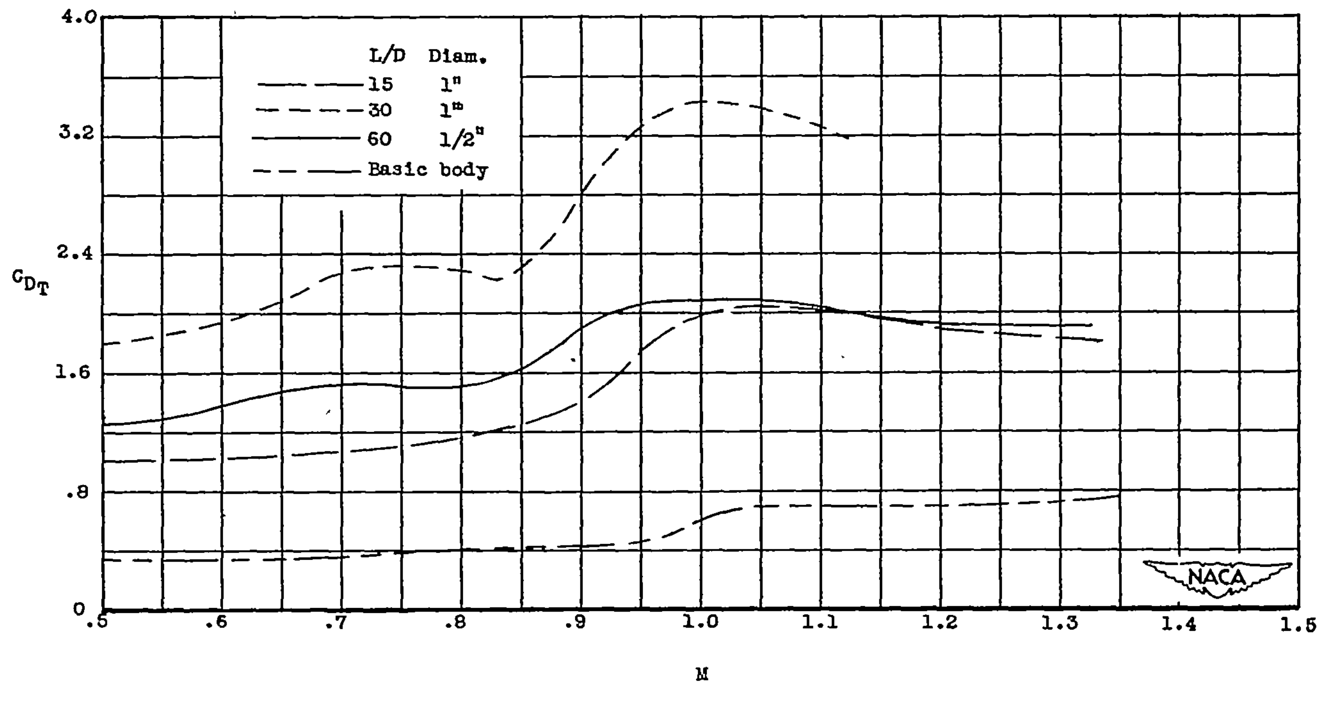

Figure 5.- Variation of total drag coefficients, based on body frontal area, with Mach number for the cylinder configurations investigated and for the basic test body.

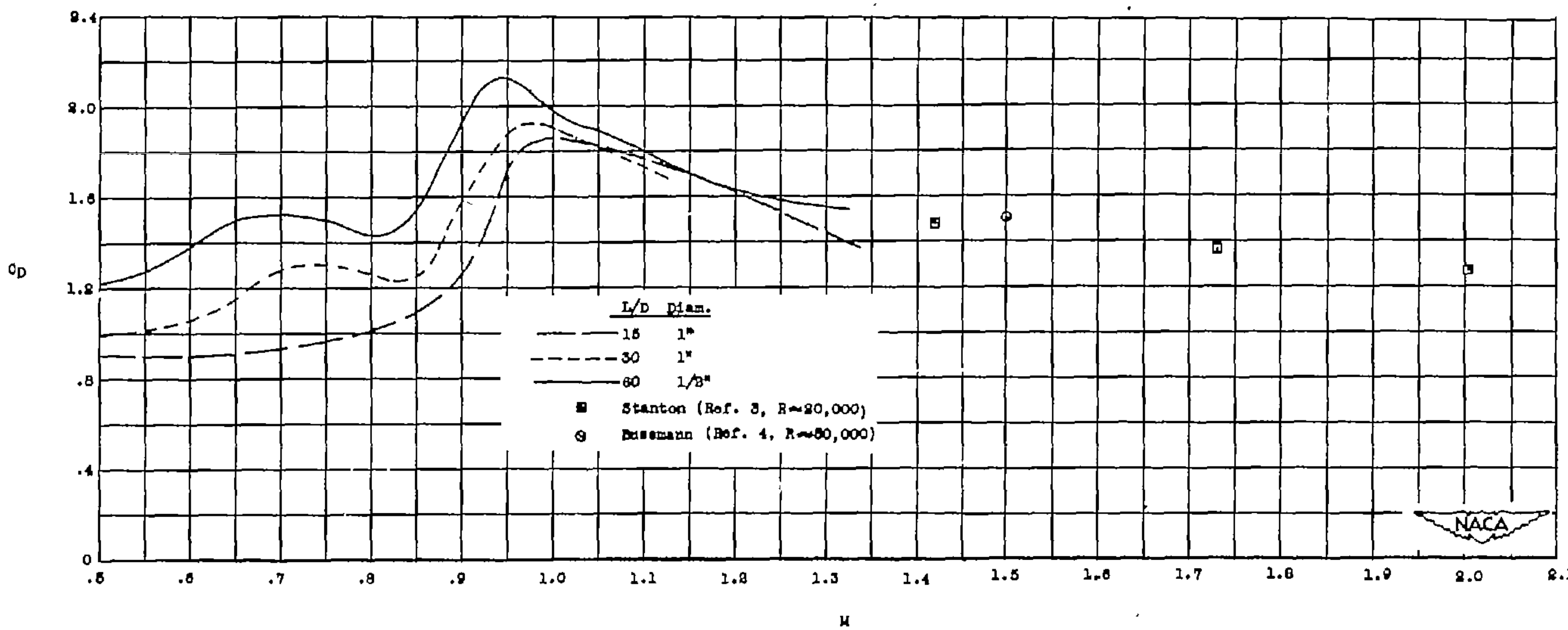

Figure 6.- Variation of cylinder drag coefficients, based on cylinder frontal area, with Mach number for the cylinder configurations tested. Also shown are two experimentally determined supersonic cylinder drag coefficients of previous investigations.

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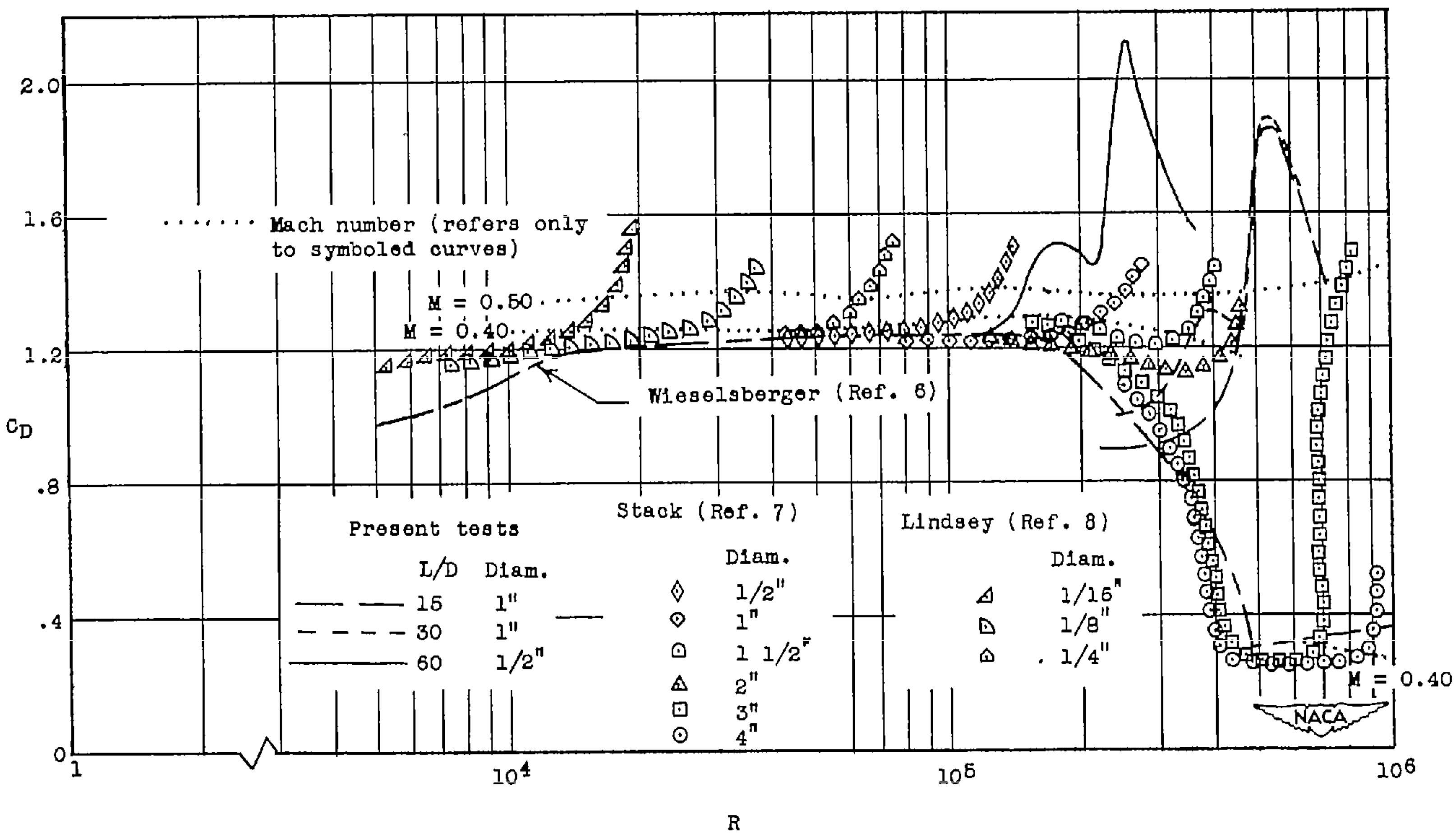

Figure 7.- Variation of the cylinder drag coefficients, based on cylinder frontal area, with Reynolds number for the cylinders of the present tests and for infinite length cylinders of previous investigations. (Symboled points do not represent experimental test points.)

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